AFRL-VA-WP-TP-2003-338

AUTOMATIC AIR COLLISION AVOIDANCE SYSTEM - DESIGN & DEVELOPMENT

D.E. Swihart
B.T. Nguyen
A.F. Barfield
E.M. Griffin

OCTOBER 2003

Approved for public release; distribution is unlimited.

AIR VEHICLES DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542

QREPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
October 2003	Conference Paper Preprint	

4. TITLE AND SUBTITLE
AUTOMATIC AIR COLLISION AVOIDANCE SYSTEM - DESIGN & DEVELOPMENT

5a. CONTRACT NUMBER IN-HOUSE
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER N/A

6. AUTHOR(S)
D.E. Swihart and B.T. Nguyen (AFRL/VACC)
A.F. Barfield (Veridian Engineering)
E.M. Griffin (Lockheed Martin Aeronautics)

5d. PROJECT NUMBER N/A
5e. TASK NUMBER N/A
5f. WORK UNIT NUMBER N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Control Systems Development and Application Branch (AFRL/VACC)
Control Sciences Division
Air Vehicles Directorate
Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7542

Veridian Engineering

Lockheed Martin Aeronautics

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-VA-WP-TP-2003-338

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Vehicles Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7542

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/VACC

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-VA-WP-TP-2003-338

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Conference paper to be presented at the 10th Conference of Australian International Aerospace Congress (AIAC), Brisbane, Australia, July 29-August 1, 2003. This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States. Report contains color.

14. ABSTRACT *(Maximum 200 Words)*
Air to air collisions are a major concern for manned aircraft especially fighters during combat training exercises. The potential of such collisions of unmanned vehicles is much higher due to the lack of a pilot to see and avoid other aircraft. A system is needed to prevent such collisions as fighters become more complex and as unmanned vehicles are used to accomplish more missions. In fact automatic collision avoidance must be developed if unmanned vehicles are to become an integral part of military air operations.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	b. ABSTRACT	c. THIS PAGE			Donald Swihart
Unclassified	Unclassified	Unclassified	SAR	14	19b. TELEPHONE NUMBER *(Include Area Code)* (937) 255-8281

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Automatic Air Collision Avoidance System – Design & Development

Swihart, D.E. (1), Nguyen B.T. (1), Barfield, A.F. (2) and Griffin, E.M. (3)

(1) Air Force Research Laboratory 1, Wright-Patterson AFB, Ohio, USA
(2) Veridian Engineering 2, Dayton, Ohio, USA
(3) Lockheed Martin Aeronautics 3, Ft. Worth, Texas, USA

Abstract

Air to air collisions are a major concern for manned aircraft especially fighters during combat training exercises. The potential of such collisions of unmanned vehicles is much higher due to the lack of a pilot to see and avoid other aircraft. A system is needed to prevent such collisions as fighters become more complex and as unmanned vehicles are used to accomplish more missions. In fact automatic collision avoidance must be developed if unmanned vehicles are to become an integral part of military air operations.

UAVs will, in some manner, have to "see and avoid" other aircraft. The Automatic Air Collision Avoidance System (Auto ACAS) will help provide this ability. Through the integration of sensors and datalinks, Auto ACAS will automatically maneuver an aircraft, at the last instant, to avoid an air-to-air collision. By emulating a normal pilot recovery maneuver, this system will form the last line of defense against air collisions, while providing nuisance free operation and safe interoperability.

While Auto ACAS is designed to prevent collisions between air vehicles, it is not intended to replace systems such as the Traffic Alert and Collision Avoidance System (TCAS), but to complement these systems by accomplishing a recovery maneuver at the last instant to prevent a collision. Existing systems provide situational awareness and traffic advisories to enable pilots or UAV operators to perform de-confliction and manual avoidance maneuvers. In contrast, Auto ACAS activates after such de-confliction and manual avoidance attempts have failed, operating in a time span that does not allow manual pilot reactions.

This paper will discuss the requirements, design, development, and proposed testing of an automatic air collision avoidance system. The separation of deconfliction and collision avoidance will be accomplished using a concept of time-to-escape. The Auto ACAS will automatically maneuver an aircraft, at the last instant, to avoid an air-to-air collision. It will function in a manner similar to a pilot avoiding a collision. It is a system that must be reliable, verifiable, and partially redundant, forming the last line of defense against collisions. It must provide nuisance free operation and allow safe interoperability. The requirements for such as system will be discussed in detail. Of particular interest are criteria to enable a safe and nuisance free operation.

Nomenclature

Auto ACAS	Automatic Air Collision Avoidance System
g	Aircraft normal acceleration unit of measure
GPS	Global Positioning System
Host aircraft	The aircraft calculating its own escape in a collision scenario
INS	Inertial Navigation System
In-network aircraft	Vehicles sharing information for collision avoidance over a datalink
Intruder aircraft	Any aircraft being considered as a collision threat to the host aircraft
TCAS	Traffic Alert and Collision Avoidance System
Time-to-escape	Time remaining until an escape from a collision is not possible
UAV	Unmanned Aerial Vehicle

1. Introduction

Tomorrow's Air Force will use unmanned air vehicles for a number of missions. High-risk missions in which pilot loss is unacceptable are ideal candidates for such vehicles. Swarming large numbers of vehicles to saturate enemy defenses and bring overwhelming force to a conflict for extended periods of time is another possibility. Whatever missions are chosen for these vehicles, their numbers and use will significantly increase in the future. We must find ways to allow safe operation with manned aircraft in the same airspace. Although collision is to be prevented, close flight with other aircraft is necessary for formation, refueling, and combat training.

To allow greater autonomy of operation, the onboard software programs for unmanned vehicles are growing at a high rate. On manned fighters, a large amount of software is considered mission critical since the pilot can intervene in the event of a program error. However, on unmanned vehicles this software and all of the programs that emulate the pilot's decision process are safety-of-flight critical. The ability to validate and verify this software is an ever-increasing problem.

One solution to insure safety is to create a separate entity within each UAV to provide some of the basic "see and avoid" capability of manned aircraft. Such an entity would be easily verified and validated. It would automatically maneuver the air vehicle, at the last instant, to avoid collision with another vehicle. It would allow safe operation of multiple UAVs and manned aircraft in close proximity. Portions of these systems would have redundant elements to provide the necessary level of safety.

2. Time-To-Escape

Air traffic advisories and warnings, flight path de-confliction, and aircraft collision avoidance seem to imply similar requirements for a vehicle. However these actions are shown to be quite different and easily separated by their time of action.

Collision avoidance is concerned with the last minute emergency maneuver to prevent aircraft loss. It is not concerned with traffic advisories/warnings or de-confliction. One way to separate these functions is to consider the time, prior to a potential collision, during which the systems are expected to operate.

The aircraft maneuvering to avoid a collision requires a finite time to obtain separation distance. Thus, a point in time can be defined, along the predicted trajectory of one aircraft, for the initiation of a defined "escape maneuver" that will just touch the other aircraft. Maneuvering at or beyond this point will not prevent the collision. This point is defined as the zero seconds time-to-escape initiation point since there is no time left to prevent the collision due to the physical maneuver constraints of the avoiding aircraft. Moving back in time from this point along the predicted trajectory yields the time available to escape a collision.

This concept of time-to-escape comes from the flight testing of an automatic ground collision avoidance system by the US Air Force at Edwards AFB in California. To illustrate the concept, consider two vehicles on a collision path as shown in Figure 1. The vehicle on the left is to initiate an automatic escape maneuver. Since the vehicles are within a "tracking zone," their trajectories are being predicted and the vehicle on the left determines the collision point. The collision avoidance system is designed to fly a path that will remain clear of the other aircraft.

An aggressive escape maneuver is defined. The maneuver is moved along the aircraft's future trajectory by advancing its initiation point. The initiation point of the maneuver that just touches the other aircraft is defined as the zero seconds time-to-escape point. Beyond this point, the escape maneuver cannot prevent collision. The point at which a pilot would initiate a last-minute escape maneuver is then established. In this example, a point 1.5 seconds prior to the zero seconds time-to-escape maneuver point is selected.

The recovery trajectory defines the temporal sphere of collision avoidance. An automatic collision avoidance system must initiate between these points, maneuvering within the collision avoidance sphere, if it is not to interfere with the pilot and provide the desired protection. The distance at which the system must initiate an escape maneuver changes with each encounter geometry. However, the time over which it must react remains constant. Thus it is easier to visualize system operation by considering temporal spheres whose radii are measured in time.

In an actual system an exclusion zone consisting of a physical distance around the target vehicle will be pre-established. The system will prevent penetration of the exclusion zone. The tracking zone in which neighboring aircraft are observed is centered on the vehicle with the automatic collision avoidance system. The collision avoidance and deconfliction spheres are projected onto the neighboring aircraft that pose a collision threat. Although useful for visualization, in practice a sphere is not calculated. The initiation point on the sphere is calculated. The sphere is the solution of all potential collisions with the vehicle from all aspects. We are interested in only one solution at any time.

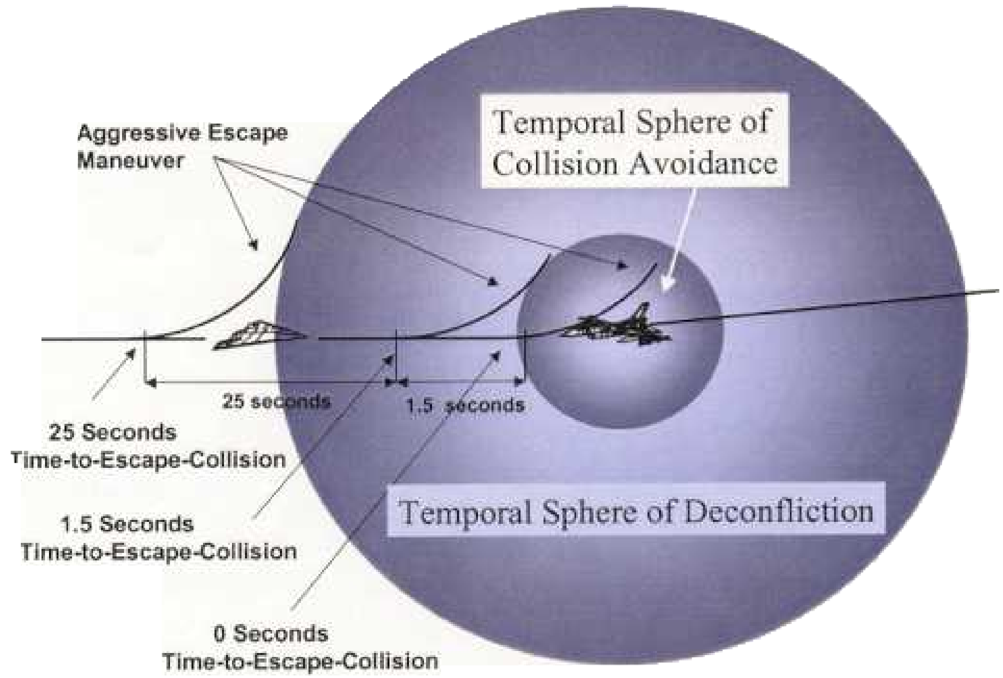

Figure 1 Time separation of functions

By using this time-to-escape parameter, we can separate the areas of interest for traffic advisories, conflict resolution, and collision prevention. UAV deconfliction operates in the 25 seconds time-to-escape range. Note that deconfliction is concerned with attempting to resolve potential collisions at a range that allows the mission to continue without major replaning. Traffic warnings and advisories for TCAS occur at in a 25 to 45 seconds time-to-escape zone. Collision avoidance assumes that TCAS advisories and autonomous deconfliction have failed to resolve the problem. The time-to-escape can also be used to evaluate system performance and nuisance potential. If the designed system commands escapes closer to the zero time-to-escape point that the point at which an aware pilot would initial an escape the system will be considered nuisance free since its operation will not interfere with normal safe pilot control.

3. Basic Requirements

Based on the concepts and discussions above, a set of system requirements were established early in the program. These requirements have not changes during the design and development phases. They are listed below:

1) The system must provide a last resort emergency automatic maneuver to prevent collisions with other air vehicles. The expected operation is between 0.5 seconds and 1.5 seconds time-to-escape.

2) The system must not interfere with normal vehicle control except to prevent aircraft loss. It must be nuisance free.

3) The system is to provide a predictable response operating as the pilot would to avoid a collision.

4) The automatic escape maneuver will be commanded only long enough to avoid the collision. Termination criteria will be established.

5) The system is to protect against unforeseen events that cause collisions.

6) The system can be relied upon to insure safe vehicle operation. It will be fully verified, validated, and tested with redundant elements as required.

7) It will make extensive use of distributed integrity monitoring to insure fail-safe operation without the use of brute force redundancy.

8) The system will be designed to work with momentary GPS or datalink loss.

9) UAVs will be required to execute an avoidance maneuver before manned aircraft are commanded to maneuver to avoid collision.

10) The system will be designed to operate in both manned and unmanned air vehicles.

11) The system is to prevent air-to-air mishaps, as well as, allow a mix of UAVs and manned aircraft to fly in the same air space.

12) The system will be designed to be modular and transportable to multiple aircraft including commercial applications.

4. Automatic Versus Manual Maneuvers

There are no automatic collision avoidance systems currently being applied within the aerospace community. This fact appears to be alarming due to the vast technology available. Yet it has been fought fiercely for various reasons. The most apparent reason is the fact that no pilot/operator is content to give up control of his/her air vehicle to a computer. Another important reason is that to accomplish the automatic function, the flight control system must interface with various avionic subsystems. The flight control system, due to its importance in the air vehicles survivability, must have several orders of magnitude greater loss of function than other avionics subsystems. Redundancy is applied to flight control systems to achieve this greater protection against loss of function. It has been thought that if redundant systems were to interface with single thread systems, the result would be that the single thread system characteristics would become dominant. This thinking has led to the many manual collision avoidance systems within the aerospace industry today. While it is true that allowing a single thread command into a redundant flight control computer in itself appears to be a dangerous event, there are methods to achieve a safe automatic maneuver.

Before these methods are discussed it seems reasonable to explain why it is important to even consider the design of an automatic system. Manual systems have been in place for many years so why should this drastic step be taken to design automatic operation. First, the basic philosophy of a manual system is that the pilot/operator will accomplish the required function within the required time. There are two operations that need to be performed, the required function plus doing it in time. To make it simple, the time can be extended to give the pilot/operator time to determine what function to accomplish. Extending the time also extends the distance between the air vehicles making things like formation, refueling, air combat training, and UAV swarming impossible for a manual system. As the time is decreased, the decision to choose the correct manual operation increases the workload on the pilot/operator.

Another problem of manual systems is the nuisance factor. A definition of a nuisance is a warning that occurs when it is perceived not required. An example might be an altitude warning where the pilot/operator gets an aural or visual warning and his perception is that everything is proper. Time marches on and the warning continues, the warning is ignored, and the aircraft hits the ground or another aircraft killing the pilot and destroying the aircraft. An automatic system solves this problem immediately since the control function is removed from the pilot/operator and the computer performs the required function.

The automatic design does not eliminate the nuisance factor. In fact it becomes more important. The pilot/operator must be satisfied that the automatic maneuver activates at the proper time and accomplishes the correct maneuver. If an automatic maneuver activates too soon, the pilot/operator will have the perception that he/she could have performed the maneuver and not need the automatic system. Of course if it activates too late the result would be catastrophic. A too early activation will also create the nuisance factor. It needs to activate after the pilot/operation would normally perform the same escape maneuver.

5.Safety Methods for Flight Control/Avionics Integration

Flight control systems are designed with redundancy to achieve the required loss of control parameter. Systems are usually triplex or quad redundant in order to achieve this parameter. In a quad system, a first failure is voted off and the system continues to operate as a triplex system. A second like failure will again be voted off and the system continues to operate as a dual system. These systems are called two-fail operate.

If a single thread avionics subsystem is integrated into the flight control system, one method of failure detection is to create a similar function utilizing redundant subsystems. For example, in Auto ACAS the INS attitude information is needed by the flight control system to enable avoidance maneuver to be executed. Suppose during a potential collision scenario the INS has a failure. Each of the quad digital flight control system computers monitors the INS and when the failure is detected the flight control rate gyros provides data for the flight control computer to calculate the needed INS attitude information for a short time period allowing the automatic maneuver to be completed.

Other methods to ensure safe avionics integration are employed. One example is to have the redundant flight control computer sending a predefined calculation with a known answer for an avionics computer to accomplish. Upon completion of the calculation the answer is sent back to the flight control computer where its accuracy is checked. Another example is to require the avionics computer to send a known coded message at a specific periodic rate to the flight control computer.

6. Sensor Versus Datalink Operation

Collision avoidance can only be accomplished if precise and timely information is available on all vehicles involved in the potential collision scenario. This information can be obtained from special on-board sensors or through the use a datalink between aircraft. For this initial Auto ACAS design and flight test effort, a specially modified datalink was chosen due to availability and cost considerations. For datalink operation, each air vehicle must have the capability to link flight parameters to each of the other air vehicles. This in-network process can function quite well with relatively small groups of vehicles, but the size of the group that can be served is limited by available bandwidth and required update rate. The datalink to be used for flight test can handle 10 aircraft and provide data updates at 10 times a second.

Active sensors such as radars or lasers can function quite well to provide collision avoidance information; however, the issues of high cost and the inability to see in all quadrants around an aircraft due to the limited field of view are unresolved. Should low cost all aspect sensors become available protection can be provided from vehicles without a datalink. In the future a combination of short range, limited field of view active sensors and limited bandwidth datalinks may provide the best solution for air to air collision protection.

7. Automatic Air Collision Avoidance Algorithm Development

The Auto ACAS algorithm is being developed cooperatively by Saab in Linkoping, Sweden and the Boeing Company in St Louis, Missouri. Saab is under contract to FMV in Sweden, and Boeing is under contract to the Air Force Research Laboratory in the US. Lockheed Martin Aircraft in Ft Worth, Texas is participating in the development and will integrate the algorithm into an F-16 for flight testing under contract to the Air Force Research Laboratory. The Air Force Flight Test Center, and the Air Force Test Pilot School at Edwards AFB, California in conjunction with 46th Test Wing at Eglin AFB, Florida will conduct the flight test effort. The Air Force Test Pilot School is implementing the algorithm on an in-flight simulation vehicle, a highly modified F-16 that can perform as a high performance manned fighter or a lower performance UAV for part of the flight test.

The algorithm operates by taking information on aircraft in the vicinity of the host vehicle and providing a filter function to determine those with the highest potential for a collision. The four vehicles posing the highest collision threat are evaluated to determine if an avoidance maneuver is needed. The Auto-ACAS algorithm does not try to identify collisions based on predicted trajectories of the aircraft. Instead it claims space along a predicted escape trajectory (time tagged positions were the aircraft will be after an avoidance is executed) which the aircraft will use in the case an avoidance maneuver is necessary. The major benefit of using an escape trajectory is that it can be predicted much more accurate than the probable trajectory which the aircraft will follow if no avoidance is executed. This is because the escape trajectory is executed automatically in a predetermined way by the Auto-ACAS algorithm, whereas the probable trajectory is affected by the change in pilot commands. The size of the claimed space is computed using knowledge of the wingspan, navigation uncertainty and accuracy

of the predicted trajectory compared to the one the automatic digital flight control system will make the aircraft follow if the escape command is given.

Each aircraft sends its predicted escape maneuver and the size of the claimed space along this track to the other aircraft, using the datalink. All aircraft will use the escape maneuvers from the different aircraft to detect a future lack of escape as shown in Figure 2. If the distance between the escape trajectories is greater than the safety distance, the track is stored as the one to use in case of avoidance. The avoidance is executed using the digital flight control system to make the aircraft follow the stored trajectory.

The escape maneuver directions are chosen to maximize the minimum distance between all aircraft. In this way the avoidance will be executed at the last possible instant and the system will thus guarantee a very low nuisance level.

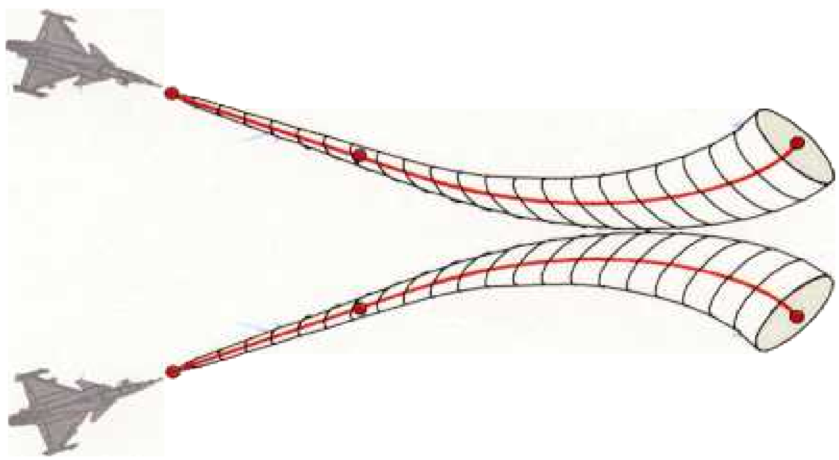

Figure 2 Collision detection using predicted escape maneuvers

In the actual system operation, three distinct escape trajectories are continuously computed for each aircraft. Three points along each trajectory, shown as red dots in the figure, are exchanged with all vehicles that pose a collision threat. Using these points the trajectories are recreated on each aircraft for use by the algorithm. The three trajectories from each aircraft are compared to find the set that allows the aircraft to continue as close as possible. The volume of increasing space along these trajectories is then added to the final set to account for position uncertainties of the aircraft.

8. Escape Maneuvers

The Auto ACAS algorithm has two basic escape maneuvers that are used to define the three escape trajectories for each aircraft. The first maneuver is a 5 g longitudinal pitch maneuver for piloted tactical aircraft, or the maximum "g available" pitch maneuver for unmanned vehicles. This is performed at whatever bank angle the aircraft might be in when an avoidance maneuver is needed. The second is a roll maneuver at the roll rate of 60 degrees per second for piloted tactical aircraft, and to at the maximum roll rate for an unmanned vehicle; the roll is followed by the same pitch maneuver as described above. The three trajectories are 1) a pure pitch maneuver, 2) a 90 degree roll to the right and a pitch maneuver, and 3) a 90 degree roll to the left and a pitch maneuver. The roll angle is selected by the algorithm to result in the maximum separation between the aircraft included in the collision avoidance calculation.

To meet the nuisance criteria, the algorithm was designed to initiate the execution of the selected escape maneuver at the last moment before the collision becomes inevitable, and to terminate the escape maneuver as soon as the minimum separation distance is reached. Thus it performs the collision avoidance with minimum interference to the pilot.

9. System Operation with Time Delays and Uncertainty

The ability of the Auto ACAS to prevent collisions while not being a nuisance to the pilot is driven by the time delays encountered by the system and the uncertainties in the parameters used by the system. These factors include the computation time and transmission delays for information shared among aircraft, the navigational accuracy of the involved aircraft, and the escape trajectories

prediction accuracy for each aircraft. It is assumed that a blended solution based on INS and GPS is available. An estimate of the expected computational and transmission delays were made and the system was designed with the ability to accommodate 300 milliseconds of delay and still provide acceptable performance. For short duration GPS losses are compensated for by allowing the navigation uncertainty to expand as the INS position drifts. The aircraft trajectories were developed to be accurate for the six seconds needed to enable an avoidance maneuver for most aircraft conditions. Extremely slow speed flight is currently not covered by the trajectories and will have to be the subject of additional development. With the above delays and uncertainties it is anticipated that nuisance free collision protection can be provided for flight with 100 to 200 feet separation for combat formations and within the required time-to-escape window for all aspect encounters.

10. The Use of a Virtual Target from a Ground Station

Testing of a collision avoidance system designed to operate during the last instance prior to a collision presents some interesting challenges. Flying aircraft towards a collision with only seconds to spare is an extremely high risk flight test. Several innovative concepts are being used to significantly reduce this risk.

One concept being applied is to assume that the system will always fail and to develop a test program to allows evaluation without endangering the test aircraft. This consists of distance offsets between the two test aircraft. The use of a selectable exclusion zone on the autopilot inputs to prevent the algorithm from maneuvering towards the other aircraft should some failure cause the escape roll angle to be in error to the point of trying roll the aircraft into the other test asset.

However, one of the most useful concepts is the use of a "virtual target" intruder aircraft. Initial algorithm flight testing will be accomplished with only one real aircraft in flight. The intruder aircraft for the test will be a computer generated virtual aircraft positioned next to and maneuvering relative to the host vehicle. To the host aircraft and to collision avoidance system, the virtual target appears to be a real collision threat. A ground station has been developed which will contain a full six-degree of freedom simulation of the intruder aircraft with an operating Auto ACAS. The ground station includes a GPS receiver and datalink hardware. The GPS provides exact time enabling the intruder aircraft to predict its escape trajectories at the same "common" time as the test aircraft. The datalink enables the inclusion of real data delays and dropouts to be evaluated with real flight hardware before two aircraft are flown together. The ground station setup is shown in Figure 3. This concept has the added benefit of significantly reducing the setup time for data runs since the virtual aircraft can be reposition with a few keystrokes on the simulation laptop computer.

11. Conclusions and Recommendations

The effort will show that a collision avoidance algorithm can be developed to safely maneuver a manned air vehicle automatically and not interfere with normal pilot operations. It will be required to only function for very short time periods to prevent potentially fatal mishap. With the system operating, a pilot should be able to safely perform all maneuvers during combat training without interference from unnecessary activation. Evaluations will show that the system would have provided protection from all of the fatal midair collisions on record.

In addition it will provide the capability for UAVs to fly closely together by removing the potential for collisions. This will be the first necessary step in providing the capability to allow swarming of hundreds or thousands of UAVs. This program is currently approaching the flight test phase and much will be learned about the suitable of the design from that testing.

Safe operation of UAVs and manned aircraft in the same airspace can be ensured by an automatic collision avoidance system as discussed in this paper. It will be used to prevent UAVs from hitting other aircraft flying in the vicinity regardless of failures that the UAVs may have sustained. The approach described can be used for both manned fighters and UAVs. Such a system will provide protection that initiates at the last instant before a collision and does not interfere with normal operations of either vehicle.

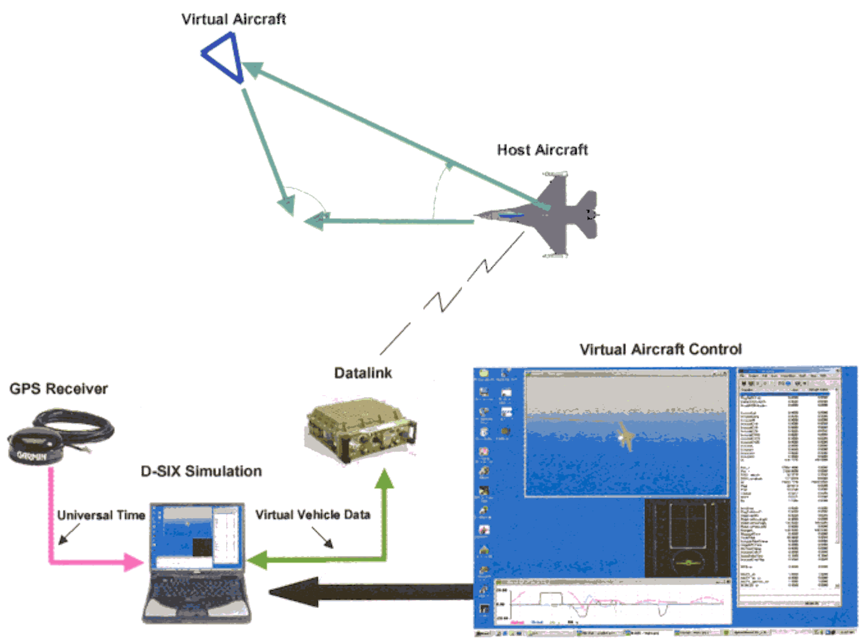

Figure 3 Ground station setup for virtual target aircraft

Position uncertainty and data latency can significantly impact such a system's operation. Both can cause an escape maneuver initiation sooner than desired. At some point, these effects will result in interference with the fighter pilot or the UAV operation. Further study of these effects and methods to accommodate the various requirements described are needed. These problems will arise for both a datalink or sensor based system.

Initial engineering assessments have concluded that a system using current datalinks could provide a nuisance free design within the time-to-escape criteria. A system meeting the requirements presented is within the realm of the possible, although additional studies and analyses are needed to quantify the actual data rates and computational capabilities needed.